

Studies on Sonar Clutter and Reverberation

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LONG-TERM GOALS

The long-term goals of this effort are to:

- Assess capability of directional arrays for inversion and reverberation studies
- Characterize acoustic clutter in a manner that will lead to its mitigation
- Improve geo-acoustic parameter extraction from reverberation data
- Construct suitable high fidelity reverberation and scattering models for model/data comparison and inversion

OBJECTIVES

The objectives of this effort are to:

- Use and continue to collect cardioid data from FORA and the NURC cardioid array, conduct cross frequency correlation studies of scattering features to assess the utility of this technology for reverberation and clutter analysis both in the cardioid frequency band and at lower frequencies.
- Continue the use of K-distribution-based techniques of Abraham to statistically characterize the various types of clutter seen on STRATAFORM including bio-clutter data from FORA.
- Continue validation and improvement efforts on a new range-dependent reverberation model and the automated geo-acoustic parameter extraction technique from reverberation data developed by the PI.
- Operate, maintain and improve FORA hardware and data acquisition systems. Help plan and participate in ocean experiments in support of sea floor scattering, bio-clutter studies and other ocean reverberation experiments.

APPROACH

The four linear sections and the cardioid array section at the head of the new Five Octave Research Array (FORA) offer a novel new way to study reverberation and scattering in shallow water. A

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limited data set from this cardioid array was collected in the 2003 Acoustic Clutter Experiment in STRATAFORM off New Jersey. Recently, additional cardioid data was collected from the FORA array during OREX-05 and from the NURC array during the 2004 Boundary Characterization sea trial. These data will serve as a starting point to improve and test the beamforming algorithms and data processing tools needed for future experiments. The NATO Undersea Research Centre has shown examples of left-right rejections in excess of 15 dB on its cardioid array (Hughes SR-329). The PI has verified that similar performance is observed using FORA during the 2003 Acoustic Clutter experiment. It has been observed that often the same reverberation and/or clutter features can be observed over a wide range of frequencies. An objective for the reverberation studies is to correlate the high frequency unambiguous feature or scatterer information from the cardioid data with the lower frequency bearing ambiguous information. More importantly, this work will attempt to define the circumstances under which good cross-frequency correlations exist. The work will also look at cross-frequency behavior of diffuse reverberation in cases where it is directional.

The PI completed an initial effort to statistically characterize the clutter seen on STRATAFORM in the 2001 Acoustic Clutter Reconnaissance Experiment (ACRE) using methods developed by Abraham. Initial results, showed many data segments of matched filtered amplitudes examined to be non-Rayleigh and that the bistatic data were significantly more non-Rayleigh than the monostatic data. The non-Rayleigh behavior is consistent with the spikiness seen in much of the ACRE 2001 polar displays. Initial looks at a small amount of the 2003 data showed them to be somewhat more Rayleigh. Much of the observed statistical differences between various data segments can be explained by considering differences in multipath, amounts of bottom insonification and the overall sound speed structure. This work is being extended to include a full statistical characterization of the STRATAFORM area for the 2003 data.

Using incoherent bottom reverberation, a manual inverse scheme first used by Preston and Ellis for Rapid Environmental Assessment (REA) [1-3] can give estimates of bottom parameters. It involves a forward model and match approach using the Generic Sonar Model (GSM) [4] and *a priori* information when possible. That scheme was automated to speed up the bottom parameter estimation process with a simulated annealing (SA) algorithm [5]. This permits near real-time higher quality performance predictions to be made. Specially designed cost functions have been developed and used to evaluate the results. Using the work of Hamilton [6] and guidance from C. Holland, the PI developed a constrained SA algorithm, which narrows the solution search space. The procedure currently uses the reverberation computations of GSM and the bottom loss estimates of ORCA but new reverberation models are being developed (see below). A multi-frequency optimization capability is part of the algorithm. The SA inversion methodology has been used on 2000 and 2001 broadband REA reverberation data taken by ARL/Penn State and NURC [7,8] as well as some HEP data and Geoclutter 2001 data [9]. The scattering strength models developed by Jackson et. al. (for example [10]), have also been incorporated into the automated inversion scheme. With the high quality of geo-acoustic ground truth available from the STRATAFORM and Malta Plateau areas, these data sets should be ideal for testing such inverse schemes. In the past the towed array based inversion algorithms developed by the PI used bearing ambiguous diffuse reverberation data and therefore were not able to map extracted geo-acoustic parameters in more than a spatially averaged sense when reverberation was anisotropic. An objective of this work will be to continue to develop the reverberation inversion algorithms to allow for inversions on anisotropic reverberation and investigate ways that inferences can be made for the low frequency inversions where reverberation data will always contain ambiguous bearing information.

A new range-dependent reverberation model based on normal modes is currently in development together with Dale Ellis of DRDC (who is working jointly with the PI) and will serve as a new forward model engine for the simulated annealing based inversion scheme already in use. Westwood's ORCA model is used to compute the eigenvalues and eigenfunctions [11] with coupling of range independent segments to be based on Evans Couple model [12]. Real 3-D effects for data taken on horizontal line arrays using directional sources already incorporated into normal mode based models like OGOPOGO by Ellis [13], will be added to the new model. Validation efforts with the PI's geo-acoustic parameter extraction technique would continue with a new range dependent forward model being a significant improvement.

Future experimental efforts to study clutter and reverberation will depend heavily on the ONR Five Octave Research Array (FORA) at Penn State, which is maintained by ARL-PSU. FORA was built under a recent DURIP award. The FORA was used in the very successful NPAL-04 and 2003 Acoustic Clutter follow-on experiments. Previously, the FORA also completed a successful sea trial, T-Mast 02, (July 2002), where a significant amount of data was collected using it as one of the primary receivers. Maintenance and system upgrades require some time on the part of the PI and in particular time for a technician to keep the FORA ready for duty. With the concurrence of ONR, improvements/repairs to FORA are usually required between sea trials.

WORK COMPLETED

For a paper at the Underwater Acoustic Measurements Conference, a constrained simulated annealing inversion technique was applied to reverberation data using the NURC cardioid array. A two-layer fluid model of the bottom was assumed. The algorithm is best at estimating compressional speeds, layer thickness and attenuations. Some directional characteristics of observed clutter and reverberation were also presented using these new cardioid receiving line arrays. The PI shows that these cardioid arrays can break the left-right ambiguity for frequencies above ~600 Hz. The data are taken from a recent experiment, the 2004 Boundary Characterization Experiment near the Malta Plateau lead by the NATO Undersea Research Centre (NURC). The area is rich in clutter objects like wrecks and mud-volcanoes and has some sub-bottom features that may be important. Sources discussed here were monostatic SUS. Some highlights of the reverberant returns from that area were shown that include the correlation of returns with man-made targets. Data analysis was done using a time domain cardioid beamforming algorithm developed by researchers at NURC with modifications by the PI for normalization. Extracted bottom parameters at the site compared fairly well with independent inversion results from Holland. Selected cardioid data from the 2003 Acoustic Clutter Experiment were also presented showing the excellent left-right rejection capabilities of FORA also.

The PI also helped plan and then participated in the OREX-05 experiment (run by NRL's R. Gauss), designed to measure bottom loss, local scattering, diffuse reverberation, pulse spreading and water-column volume scattering off the Oregon Coast. This data set represents a much more complete cardioid data collection effort using the FORA. In this time period, additional new pieces of software were developed by the PI to process cardioid data from the FORA.

The PI also has been involved in helping M.I.T. plan for a follow on effort to the Acoustic Clutter program concentrating on biologic clutter. The FORA is intended as the primary receiver in a new experimental component of an Acoustic Imaging initiative.

The PI has also spent some effort in overseeing the 'care and feeding' of the new ONR Five Octave Research Array (FORA) at Penn State in preparation for the NRL OREX-05 experiment. In addition,

plans for a FORA refurbishment effort are being developed to prepare for the 2006 Acoustic Imaging Experiment.

Efforts to construct a range dependent normal mode based reverberation models have continued. ORCA is used to generate the eigenvalues and eigenfunctions for an environment and then modifications to Ellis' techniques are being used to build the reverberation models.

RESULTS

Recent results from reverberation analysis using the cardioid low frequency array from NURC on data from the 2004 Boundary Characterization sea trial were reported in [14]. As an example, Figure 1 below shows a polar display of monostatic reverberation from the Malt Plateau vs. angle and range. Data was collected on the NURC cardioid towed array in a 1000 Hz band centered at 1200 Hz. Reverberation is color-coded vs. intensity. The source was an LFM pulse, 1.5 s in duration. Left right ambiguity is broken by the cardioid beamformer and shows excellent left-right rejection on various clutter features including three wrecks, the Campo Vega oil rig and the Ragusa Ridge (extending more than 10 nm, along a N-S line).

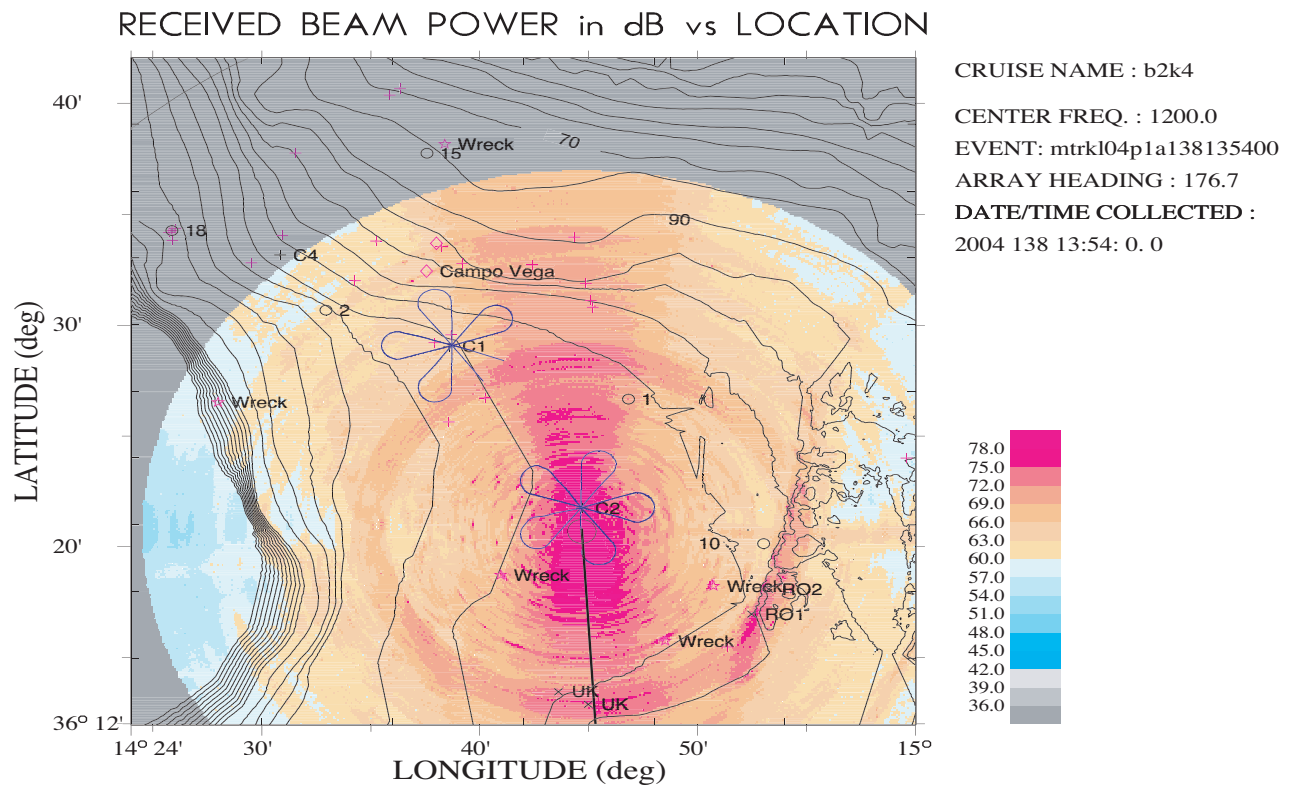


Fig. 1. Polar plot of the monostatic matched filtered reverberation on the Malta Plateau from a pulse in a 1000 Hz band centered at 1200 Hz. Left-right ambiguity is broken by the cardioid beamformer and shows excellent left-right rejection on various clutter features. Among these features are three wrecks, the Campo Vega oil rig and the Ragusa Ridge (extending more than 10 nm, N-S).

IMPACT/APPLICATIONS

A better understanding of sonar clutter is key to improving sonar usability in shallow water. The new FORA and NURC cardioid arrays are exciting new tools for ocean acoustic researchers. A wide area-averaged bottom parameter estimation technique using simulated annealing for Rapid Environmental Assessment such as described here and that utilizes directional reverberation measurements could provide a quick way to estimate bottom parameters and hence give improved sonar performance estimates.

TRANSITIONS

Inversion techniques similar to those described above have recently been applied to select data from recent HEP experiments as part of ONR 6.2 efforts lead by Dr. R. Wayland in support of the TAMBDA program at NAWC. In addition, an effort is underway to incorporate the above inversion concepts and reverberation models into a multi-static parallel toolbox – an effort that is being led by J. Joseph at NAWC.

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